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APPARATUS AND METHODS FOR MULTI-STEP
CHEMICAL MECHANICAL POLISHING

Background

The present invention relates to apparatus and methods for chemical mechanical polishing a substrate.

An integrated circuit is typically formed on a substrate by the sequential deposition of conductive, semiconductive or insulative layers on a silicon wafer. One fabrication step involves depositing a filler layer over a patterned stop layer, and planarizing the filler layer until the stop layer is exposed. For example, trenches or holes in an insulative layer may be filled with a conductive layer. After planarization, the portions of the conductive layer remaining between the raised pattern of the insulative layer form vias, plugs and lines that provide conductive paths between thin film circuits on the substrate.

Chemical mechanical polishing (CMP) is one accepted method of planarization. This planarization method typically requires that the substrate be mounted on a carrier or polishing head. The exposed surface of the substrate is placed against a rotating polishing pad. The polishing pad may be either a "standard" (non-fixed-abrasive) pad or a fixed-abrasive pad. A standard pad has a durable roughened surface, whereas a fixed-abrasive pad has abrasive particles held in a containment media. The carrier head provides a controllable load, i.e., pressure, on the substrate to push it against the polishing pad. A polishing slurry, including at least one chemically-reactive agent,

and abrasive particles if a standard pad is used, is supplied to the surface of the polishing pad.

An effective CMP process not only provides a high polishing rate, but also provides a substrate surface which is finished (lacks small-scale roughness) and flat (lacks large-scale topography). The polishing rate, finish and flatness are determined by the pad and slurry combination, the relative speed between the substrate and pad, and the force pressing the substrate against the pad. The polishing rate sets the time needed to polish a layer, which in turn sets the maximum throughput of the CMP apparatus.

During CMP operations, the polishing pad needs to be replaced periodically. For a fixed-abrasive pad, the substrate wears away the containment media to expose the embedded abrasive particles. Thus, the fixed-abrasive pad is gradually consumed by the polishing process. After a sufficient number of polishing runs (e.g., forty to fifty) the fixed-abrasive pad needs to be replaced. For a standard pad, the substrate thermally and mechanically damages the polishing pad and causes the pad's surface to become smoother and less abrasive. Therefore, standard pads must be periodically "conditioned" to restore a roughened texture to their surface. After a sufficient number of conditioning operations (e.g., three hundred to four hundred), the conditioning process consumes the pad or the pad is unable to be properly conditioned. The pad must then be replaced.

An advantage of fixed-abrasive polishing pads is that they do not need to be conditioned.

One problem encountered in the CMP process is difficulty in replacing the polishing pad. The polishing pad may be attached to the platen surface with an adhesive.

Significant physical effort is often required to peel the polishing pad away from the platen surface. The adhesive then must be removed from the platen surface by scraping and washing with a solvent. A new polishing pad can then be adhesively attached to the clean surface of the platen. While this is happening, the platen is not available for the polishing of substrates, resulting in a decrease in polishing throughput. This problem is even more acute for fixed-abrasive pads, which need to be replaced more often than standard polishing pads. Thus, although the fixed-abrasive pads do not need to be conditioned, the use of fixed-abrasive pads in a CMP apparatus results in a higher cost of operation.

Summary

In one aspect, the invention is directed to method of chemical mechanical polishing that includes contacting a substrate with a generally linear fixed-abrasive polishing sheet releasably secured to a first platen, the polishing sheet having a width greater than a diameter of the substrate, creating relative motion between the substrate and polishing sheet to polish the substrate, incrementally advancing the polishing sheet in a linear direction across the top surface of the first platen after polishing at the first platen, contacting a substrate with a generally circular fixed-abrasive polishing pad secured to a second platen, and rotating the second platen to create relative motion between the substrate and the polishing pad to polishing the substrate.

In another aspect, the invention is directed to a method of chemical mechanical polishing that includes

contacting a substrate with a generally linear non-fixed-abrasive polishing sheet releasably secured to a first platen, the polishing sheet having a width greater than a diameter of the substrate, relative motion is created

5 between the substrate and polishing sheet to polish the substrate, incrementally advancing the polishing sheet in a linear direction across the top surface of the first platen after polishing at the first platen, contacting a substrate with a generally circular polishing pad secured to a second
10 platen, and rotating the second platen to create relative motion between the substrate and the polishing pad to polishing the substrate.

Implementations of the invention may include one or more of the following features. The circular polishing pad
15 may comprise a fixed-abrasive polishing material or a non-fixed-abrasive polishing material.

In another aspect, the invention is directed to a method of chemical mechanical polishing that includes contacting a substrate with a generally circular polishing
20 pad secured to a first platen, rotating the second platen to create relative motion between the substrate and the polishing pad to polishing the substrate, following polishing at the first platen, contacting a substrate with a generally linear polishing sheet releasably secured to a
25 second platen, the polishing sheet having a width greater than a diameter of the substrate, creating relative motion between the substrate and polishing sheet to polish the substrate, and incrementally advancing the polishing sheet in a linear direction across the top surface of the second
30 platen after polishing at the second platen.

Implementations of the invention may include one or

more of the following features. The polishing sheet may
comprise a fixed-abrasive polishing material or a non-fixed-
abrasive polishing material, and the polishing pad may
comprise a fixed-abrasive polishing material or a non-fixed-
5 abrasive polishing material.

In another aspect, the invention is directed to a
method of chemical mechanical polishing that includes
contacting a substrate with a first generally linear
polishing sheet releasably secured to a first platen, the
10 first polishing sheet having a width greater than a diameter
of the substrate, creating relative motion between the
substrate and first polishing sheet to polish the substrate,
incrementally advancing the first polishing sheet in a
linear direction across the top surface of the first platen
15 after polishing at the first platen, contacting a substrate
with a second generally linear polishing sheet releasably
secured to a second platen, the second polishing sheet
having a width greater than a diameter of the substrate,
creating relative motion between the substrate and second
20 polishing sheet to polish the substrate, and incrementally
advancing the second polishing sheet in a linear direction
across the top surface of the second platen after polishing
at the second platen. The first polishing sheet and the
second polishing sheet include a fixed-abrasive polishing
25 sheet and a non-fixed abrasive polishing sheet.

Implementations of the invention may include one or
more of the following features. The first polishing sheet
may comprise a fixed-abrasive polishing material and the
second polishing sheet may comprise a non-fixed abrasive
30 polishing material, or the first polishing sheet may
comprises a non-fixed-abrasive polishing material and the

second polishing sheet may comprise a fixed abrasive polishing material.

In another aspect, the invention is directed to an apparatus for polishing a substrate that includes a controller configured to cause a substrate carrier mechanism to perform these methods.

Advantages of the invention may include the following. More substrates can be polished without replacing the polishing pad, thereby reducing downtime of the CMP apparatus and increasing throughput. An sheet of advanceable fixed-abrasive polishing material can be provided in a polishing cartridge. It is easy to remove and replace the polishing cartridge from a platen. Either a circular platen or a rectangular platen (to which the polishing cartridge would be attached) can be mounted at each polishing station of the CMP apparatus. The polishing apparatus gains the advantages associated with fixed-abrasive polishing materials. A rotating carrier head can be used to press the substrate against the rotating polishing sheet.

Other features and advantages will be apparent from the following description, including the drawings and claims.

Brief Description of the Drawings

FIG. 1 is a schematic exploded perspective view of a chemical mechanical polishing apparatus.

FIG. 2 is a top view of the CMP apparatus of FIG. 1.

FIG. 3A is a top view of the first polishing station of the CMP apparatus of FIG. 1.

FIG. 3B is a schematic exploded perspective view of

a rectangular platen and a polishing cartridge.

FIG. 3C is a schematic perspective view of a polishing cartridge attached to a rectangular platen.

FIG. 4 is a schematic cross-sectional view of a fixed abrasive polishing sheet.

FIG. 5A is a schematic cross-sectional view of a feed roller of the polishing cartridge of FIG. 3B.

FIG. 5B is a schematic exploded perspective view of the connection of the feed roller to the rectangular platen.

FIG. 6 is a schematic cross-sectional view of the polishing station of FIG. 3A.

FIG. 7 is a schematic diagrammatic view of a polishing sheet advancing system.

FIG. 8 is a schematic partially cross-sectional and partially perspective view of a contamination guard system for a platen with an advanceable polishing sheet.

FIG. 9 is a schematic cross-sectional view of a polishing station having an optical endpoint detection system.

FIG. 10 is a schematic cross-sectional view of a platen and polishing pad of a second polishing station.

FIG. 11 is a schematic cross-sectional view of a platen and polishing pad of a final polishing station.

Detailed Description

Referring to FIGS. 1 and 2, one or more substrates 10 will be polished by a chemical mechanical polishing apparatus 20. A description of a similar polishing apparatus may be found in U.S. Patent No. 5,738,574, the entire disclosure of which is incorporated herein by reference. Polishing apparatus 20 includes a machine base

22 with a table top 23 that supports a series of polishing stations, including a first polishing station 25a, a second polishing station 25b, and a final polishing station 25c, and a transfer station 27. Transfer station 27 serves multiple functions, including receiving individual substrates 10 from a loading apparatus (not shown), washing the substrates, loading the substrates into carrier heads, receiving the substrates from the carrier heads, washing the substrates again, and finally, transferring the substrates back to the loading apparatus.

Each polishing station includes a rotatable platen.

At least one of the polishing stations, such as first station 25a, includes a polishing cartridge 102 mounted to a rotatable, rectangular platen 100. The polishing cartridge 102 includes a linearly advanceable sheet or belt of fixed-abrasive polishing material. The remaining polishing stations, e.g., second polishing station 25b and final polishing station 25c, may include "standard" polishing pads 32 and 34, respectively, each adhesively attached to a circular platen 30. Each platen may be connected to a platen drive motor (not shown) that rotates the platen at thirty to two hundred revolutions per minute, although lower or higher rotational speeds may be used. Assuming that substrate 10 is an "eight-inch" (200 mm) diameter disk, then rectangular platen 100 may be about twenty inches on a side, and circular platen 30 and polishing pads 32 and 34 may be about thirty inches in diameter.

Each polishing station 25a, 25b and 25c also includes a combined slurry/rinse arm 52 that projects over the associated polishing surface. Each slurry/rinse arm 52 may include two or more slurry supply tubes to provide a

polishing liquid, slurry, or cleaning liquid to the surface of the polishing pad. For example, the polishing liquid dispensed onto the fixed-abrasive polishing sheet at first polishing station 25a will not include abrasive particles, whereas the slurry dispensed onto the standard polishing pad at second polishing station 25b will include abrasive particles. If final polishing station 25a is used for buffing, the polishing liquid dispensed onto the polishing pad at that station would not include abrasive particles. Typically, sufficient liquid is provided to cover and wet the entire polishing pad. Each slurry/rinse arm also includes several spray nozzles (not shown) which provide a high-pressure rinse at the end of each polishing and conditioning cycle.

The polishing stations that include a standard polishing pad, i.e., polishing station 25b and 25c, may include an optional associated pad conditioner apparatus 40.

The polishing stations that include a fixed-abrasive polishing pad, i.e., polishing station 25a, may include an optional unillustrated cleaning apparatus to remove grit or polishing debris from the surface of the polishing sheet. The cleaning apparatus may include a rotatable brush to sweep the surface of the polishing sheet and/or a nozzle to spray a pressurized cleaning liquid, e.g., deionized water, onto the surface of the polishing sheet. The cleaning apparatus can be operated continuously, or between polishing operations. In addition, the cleaning apparatus could be stationary, or it could sweep across the surface of the polishing sheet.

In addition, optional cleaning stations 45 may be positioned between polishing stations 25a and 25b, between

polishing stations 25b and 25c, between polishing station 25c and transfer station 27, and between transfer station 27 and polishing station 25a, to clean the substrate as it moves between the stations.

5 A rotatable multi-head carousel 60 is supported above the polishing stations by a center post 62 and is rotated about a carousel axis 64 by a carousel motor assembly (not shown). Carousel 60 includes four carrier head systems mounted on a carousel support plate 66 at equal
10 angular intervals about carousel axis 64. Three of the carrier head systems receive and hold substrates, and polish them by pressing them against the polishing sheet of station 25a and the polishing pads of stations 25b and 25c. One of the carrier head systems receives a substrate from and
15 delivers a substrate to transfer station 27.

 Each carrier head system includes a carrier or carrier head 80. A carrier drive shaft 78 connects a carrier head rotation motor 76 (shown by the removal of one quarter of the carousel cover) to carrier head 80 so that
20 each carrier head can independently rotate about its own axis. In addition, each carrier head 80 independently laterally oscillates in a radial slot 72 formed in carousel support plate 66.

 The carrier head 80 performs several mechanical
25 functions. Generally, the carrier head holds the substrate against the polishing surface, evenly distributes a downward pressure across the back surface of the substrate, transfers torque from the drive shaft to the substrate, and ensures that the substrate does not slip out from beneath the
30 carrier head during polishing operations. A description of a suitable carrier head may be found in U.S. Patent

Application Serial No. 08/861,260, entitled a CARRIER HEAD
WITH a FLEXIBLE MEMBRANE FOR a CHEMICAL MECHANICAL POLISHING
SYSTEM, filed May 21, 1997 by Steven M. Zuniga et al.,
assigned to the assignee of the present invention, the
entire disclosure of which is incorporated herein by
reference.

Referring to FIGS. 3A, 3B, and 3C, polishing
cartridge 102 is detachably secured to rectangular platen
100 at polishing station 25a. Polishing cartridge 102
includes a feed roller 130, a take-up roller 132, and a
generally linear sheet or belt 110 of a polishing pad
material. An unused or "fresh" portion 120 of the polishing
sheet is wrapped around feed roller 130, and a used portion
122 of the polishing sheet is wrapped around take-up roller
132. A rectangular exposed portion 124 of the polishing
sheet that is used to polish substrates extends between the
used and unused portions 120, 122 over a top surface 140 of
rectangular platen 100.

The rectangular platen 100 can be rotated (as shown
by phantom arrow "A" in FIG. 3A) to rotate the exposed
portion of the polishing sheet and thereby provide relative
motion between the substrate and the polishing sheet during
polishing. Between polishing operations, the polishing
sheet can be advanced (as shown by phantom arrow "B" in FIG.
3A) to expose an unused portion of the polishing sheet.
When the polishing material advances, polishing sheet 110
unwraps from feed roller 130, moves across the top surface
of the rectangular platen, and is taken up by take-up roller
132.

Referring to FIG. 4, polishing sheet 110 is
preferably a fixed-abrasive polishing pad having a polishing

surface 112. The fixed-abrasive polishing pad may be about twenty inches wide and about 0.005 inches thick. The fixed-abrasive polishing pad may include an upper layer 114 and a lower layer 116. Upper layer 114 is an abrasive composite layer composed of abrasive grains held or embedded in a binder material. The abrasive grains may have a particle size between about 0.1 and 1500 microns. Examples of such grains include silicon oxide, fused aluminum oxide, ceramic aluminum oxide, green silicon carbide, silicon carbide, chromia, alumina zirconia, diamond, iron oxide, ceria, cubic boron nitride, garnet and combinations thereof. The binder material may be derived from a precursor which includes an organic polymerizable resin which is cured to form the binder material. Examples of such resins include phenolic resins, urea-formaldehyde resins, melamine formaldehyde resins, acrylated urethanes, acrylated epoxies, ethylenically unsaturated compounds, aminoplast derivatives having at least one pendant acrylate group, isocyanurate derivatives having at least one pendant acrylate group, vinyl ethers, epoxy resins, and combinations thereof. Lower layer 116 is a backing layer composed of a material such as a polymeric film, paper, cloth, a metallic film or the like.

A fixed-abrasive polishing sheet having a polyester belt that carries silicon oxide abrasive particles is available from 3M Corporation of Minneapolis, Minnesota.

Referring again to FIGS. 3A, 3B and 3C, a transparent strip 118 is formed along the length of polishing sheet 110. The transparent strip may be positioned at the center of the sheet, and may be about 0.6 inches wide. Transparent strip 118 may be formed by excluding abrasive particles from this region of the

containment media during fabrication of the polishing sheet.

The transparent strip will be aligned with an aperture or transparent window 154 in rectangular platen 100 to provide optical monitoring of the substrate surface for end point detection, as discussed in greater detail below.

The feed and take-up rollers 130 and 132 should be slightly longer than the width of polishing sheet 110. The rollers 130, 132 may be plastic or metal cylinders about 20" long and about 2" in diameter. Referring to FIG. 5A, the opposing end faces 134 of feed roller 130 (only the feed roller is shown, but the take-up roller would be constructed similarly) each include a recess 136 which will engage a support pin 164 (see FIGS. 3B and 5B) that will secure the roller to the platen. In addition, both end faces 134 of each roller may be chamfered at edge 138 to prevent polishing sheet 110 from slipping laterally.

Returning to FIGS. 3A, 3B and 3C, rectangular platen 100 includes a generally planar rectangular top surface 140 bounded by a feed edge 142, a take-up edge 144, and two parallel lateral edges 146. A groove 150 (shown in phantom in FIGS. 3A and 3C) is formed in top surface 140. The groove 150 may be a generally-rectangular pattern that extends along edges 142-146 of top surface 140. A passage 152 through platen 100 connects groove 150 to a vacuum source 200 (see FIG. 6). When passage 152 is evacuated, exposed portion 124 of polishing sheet 110 is vacuum-chucked to top surface 140 of platen 100. This vacuum-chucking helps ensure that lateral forces caused by friction between the substrate and the polishing sheet during polishing do not force the polishing sheet off the platen. A central region 148 of top surface 140 is free from grooves to

prevent potential deflection of the polishing sheet into the grooves from interfering with the polishing uniformity. As discussed, aperture 154 is formed in top surface 140 of rectangular platen 100. An unillustrated compressible backing pad may be placed on the top surface of the platen to cushion the impact of the substrate against the polishing sheet. In addition, platen 100 may include an unillustrated shim plate. Shim plates of differing thickness may be attached to the platen to adjust the vertical position of the top surface of platen. The compressible backing pad can be attached to the shim plate.

The rectangular platen 100 also includes four retainers 160 that hold feed and take-up rollers 130 and 132 at feed and take-up edges 142 and 144, respectively. Each retainer 160 includes an aperture 162. At each retainer, a pin 164 extends through aperture 162 and into recess 136 (see FIG. 5A) to rotatably connect rollers 130 and 132 to platen 100. To secure polishing cartridge 102 to platen 100, feed roller 130 is slipped into the space between the two retainers along feed edge 142, and two pins 164 are inserted through opposing apertures 162 in retainers 160 to engage the two opposing recesses in the feed roller. Similarly, take-up roller 132 is mounted to platen 100 by slipping it into place between the two retainers along take-up edge 144, and inserting two pins 164 through the opposing apertures 162 to engage the two opposing recesses in the take-up roller.

As shown in FIG. 5B, one pin 164 from each roller 130, 132 may pass through a gear assembly 166a, 166b (see also FIG. 7) that controls the rotation of the pin, and thus the rotation of the roller. Gear assembly 166a may be

secured to the side of rectangular platen 100 by screws or bolts 167, and a cover 168 may protect gear assembly 166 from contamination during the polishing process.

The rollers 130 and 132 need to be positioned sufficiently below top surface 140 so that the polishing sheet stays in contact with the feed and take-up edges 142 and 144 of the platen when the entire polishing sheet is wound around either roller. This assists in the creation of a seal between the polishing sheet and the rectangular platen when vacuum is applied to passage 152 to vacuum-chuck the polishing sheet to the platen. Furthermore, feed edge 142 and take-up edge 144 of the platen are rounded to prevent abrasion of the underside of the polishing sheet as it moves across the platen.

As illustrated by FIG. 6, rectangular platen 100 is secured to a rotatable platen base 170. Rectangular platen 100 and platen base 170 may be joined by several peripheral screws 174 counter-sunk into the bottom of platen base 170.

A first collar 176 is connected by screws 178 to the bottom of platen base 170 to capture the inner race of an annular bearing 180. A second collar 182, connected to table top 23 by a set of screws 183, captures the outer race of annular bearing 180. Annular bearing 180 supports rectangular platen 100 above table top 23 while permitting the platen to be rotated by the platen drive motor.

A platen motor assembly 184 is bolted to the bottom of table top 23 through a mounting bracket 186. Platen motor assembly 184 includes a motor 188 having an output drive shaft 190. Output shaft 190 is fitted to a solid motor sheath 192. A drive belt 194 winds around motor sheath 192 and a hub sheath 196. Hub sheath 196 is joined

to platen base 170 by a platen hub 198. Thus, motor 188 may rotate rectangular platen 100. Platen hub 198 is sealed to lower platen base 170 and to hub sheath 196.

A pneumatic control line 172 extends through rectangular platen 100 to connect passage 152, and thus grooves 150, to a vacuum or pressure source. The pneumatic line 172 may be used both to vacuum-chuck the polishing sheet, and to power or activate a polishing sheet advancement mechanism, described in greater detail below.

The platen vacuum-chucking mechanism and the polishing sheet advancing mechanism may be powered by a stationary pneumatic source 200 such as a pump or a source of pressurized gas. Pneumatic source 200 is connected by a fluid line 202 to a computer controlled valve 204. The computer controlled valve 204 is connected by a second fluid line 206 to a rotary coupling 208. The rotary coupling 208 connects the pneumatic source 200 to an axial passage 210 in a rotating shaft 212, and a coupling 214 connects axial passage 210 to a flexible pneumatic line 216.

Vacuum-chucking passage 152 can be connected to flexible pneumatic line 216 via pneumatic line 172 through rectangular platen 100, a passage 220 in platen base 170, a vertical passage 222 in platen hub 198, and a passageway 224 in hub sheath 196. O-rings 226 may be used to seal each passageway.

A general purpose programmable digital computer 280 is appropriately connected to valve 204, platen drive motor 188, carrier head rotation motor 76, and a carrier head radial drive motor (not shown). Computer 280 can open or close valve 204, rotate platen 100, rotate carrier head 80 and move carrier head along slot 72.

Referring to FIGS. 5B and 7, the polishing cartridge and platen includes a sheet advancing mechanism to incrementally advance polishing sheet 110. Specifically, gear assembly 166a adjacent feed roller 130 includes a feed gear wheel 230 that is rotationally fixed to pin 164. The feed gear wheel 230 engages a ratchet 232 that is held in place by an escapement clutch 234. Ratchet 232 and escapement clutch 234 may be contained in gear assembly 166a, and thus are not shown in FIG. 5B.

The gear assembly 166b (not shown in FIG. 5B) adjacent take-up roller 132 includes a take-up gear wheel 240 that is rotationally fixed to pin 164. The take-up gear wheel 240 engages a slip clutch 244 and a torsion spring 242. The torsion spring 242 applies a constant torque that tends to rotate the take-up roller and advance the polishing sheet. In addition, slip clutch 244 prevents take-up roller 132 from rotating counter to the torque applied by torsion spring 242.

While ratchet 232 engages feed gear wheel 230 on feed roller 130, polishing sheet 110 cannot advance. Thus, torsion spring 242 and slip clutch 244 maintain polishing sheet 110 in a state of tension with the exposed portion of the polishing sheet stretched across the top surface of rectangular platen 100. However, if escapement clutch 234 is activated, ratchet 232 disengages from feed gear wheel 230, and take-up roller 132 can rotate until feed gear wheel 230 reengages ratchet 232, e.g., by one notch. Escapement clutch 234 can be pneumatically controlled by the same pneumatic line 172 that is used to vacuum chuck the polishing sheet 110 to platen 100. An unillustrated tube may connect pneumatic line 172 to gear assembly 166a. If a

positive pressure is applied to pneumatic line 172,
escapement clutch 234 is activated to move ratchet 232.
This permits the feed roller to rotate one notch, with a
corresponding advancement of the polishing sheet across the
5 platen. A separate pneumatic line could control escapement
clutch 234, although this would require an additional rotary
feed-through. Alternately, the linear drive mechanism may
include a ratchet 169 (see FIG. 5B) that engages one of the
gear assemblies to manually advance the polishing sheet.

10 A potential problem during polishing is that the
unused portion of the polishing sheet may become
contaminated by slurry or polishing debris. Referring to
FIG. 8, a portion 156 of rectangular platen 100 may project
over feed roller 130 so that the feed roller is located
15 beneath the platen top surface and inwardly of the feed edge
of the platen. As such, the body of the platen shields the
feed roll from contamination. Alternately, an elongated
cover with a generally semicircular cross-section can be
positioned around each roller. The elongated cover can be
20 secured to the retainers. The polishing sheet would pass
through a thin gap between the cover and the platen.

In addition, a contamination guard 250 can be
positioned over the feed edge of the rectangular platen.
The contamination guard includes a frame 252 that extends
25 along the width of polishing sheet 110 and is suspended
above the sheet to form a narrow gap 254. A fluid source
(not shown), such as a pump, forces a gas, such as air,
through gap 254 via passageway 256 to provide a uniform air
flow as shown by arrows 258. The flow of air through gap
30 254 prevents the polishing liquid or polishing debris from
passing beneath contamination guard 250 and contaminating

the unused portion of the polishing sheet on feed roller 130.

Referring to FIG. 9, an aperture or hole 154 is formed in platen 100 and is aligned with transparent strip 118 in polishing sheet 110. The aperture 154 and transparent strip 118 are positioned such that they have a "view" of substrate 10 during a portion of the platen's rotation, regardless of the transnational position of the polishing head. An optical monitoring system 90 is located below and secured to platen 100, e.g., between rectangular platen 100 and platen base 170 so that it rotates with the platen. The optical monitoring system includes a light source 94 and a detector 96. The light source generates a light beam 92 which propagates through aperture 154 and transparent strip 118 to impinge upon the exposed surface of substrate 10.

In operation, CMP apparatus 20 uses optical monitoring system 90 to determine the thickness of a layer on the substrate, to determine the amount of material removed from the surface of the substrate, or to determine when the surface has become planarized. The computer 280 may be connected to light source 94 and detector 96.

Electrical couplings between the computer and the optical monitoring system may be formed through rotary coupling 208.

The computer may be programmed to activate the light source when the substrate overlies the window, to store measurements from the detector, to display the measurements on an output device 98, and to detect the polishing endpoint, as described in U.S. Patent Application Serial No. 08/689,930, entitled METHOD OF FORMING A TRANSPARENT WINDOW IN A POLISHING PAD FOR A CHEMICAL MECHANICAL POLISHING

APPARATUS, filed 8/16/96 by Manush Birang et al., assigned to the assignee of the present invention, the entire disclosure of which is incorporated herein by reference.

In operation, exposed portion 124 of polishing sheet 110 is vacuum-chucked to rectangular platen 100 by applying a vacuum to passage 152. A substrate is lowered into contact with polishing sheet 110 by carrier head 80, and both platen 100 and carrier head 80 rotate to polish the exposed surface of the substrate. After polishing, the substrate is lifted off the polishing pad by the carrier head. The vacuum on passage 152 is removed. The polishing sheet is advanced by applying a positive pressure to pneumatic line 172 to trigger the advancement mechanism. This exposes a fresh segment of the polishing sheet. The polishing sheet is then vacuum-chucked to the rectangular platen, and a new substrate is lowered into contact with the polishing sheet. Thus, between each polishing operation, the polishing sheet may be advanced incrementally. If the polishing station includes a cleaning apparatus, the polishing sheet may be washed between each polishing operation.

The amount that the sheet may be advanced will depend on the desired polishing uniformity and the properties of the polishing sheet, but should be on the order of 0.05 to 1.0 inches, e.g., 0.4 inch, per polishing operation. Assuming that the exposed portion 124 of polishing sheet is 20 inches long and the polishing sheet advances 0.4 inches after each polishing operation, the entire exposed portion of the polishing sheet will be replaced after about fifty polishing operations.

Referring to FIG. 10, at second polishing station

25b, the circular platen may support a circular polishing pad 32 having a roughed surface 262, an upper layer 264 and a lower layer 266. Lower layer 266 may be attached to platen 30 by a pressure-sensitive adhesive layer 268. Upper layer 264 may be harder than lower layer 266. For example, upper layer 264 may be composed of microporous polyurethane or polyurethane mixed with a filler, whereas lower layer 266 may be composed of compressed felt fibers leached with urethane. A two-layer polishing pad, with the upper layer composed of IC-1000 or IC-1400 and the lower layer composed of SUBA-4, is available from Rodel, Inc. of Newark, Delaware (IC-1000, IC-1400 and SUBA-4 are product names of Rodel, Inc.). A transparent window 269 may be formed in polishing pad 32 over an aperture 36 in platen 30.

Referring to FIG. 11, at final polishing station 25c, the platen may support a polishing pad 34 having a generally smooth surface 272 and a single soft layer 274. Layer 274 may be attached to platen 30 by a pressure-sensitive adhesive layer 278. Layer 274 may be composed of a napped poromeric synthetic material. A suitable soft polishing pad is available from Rodel, Inc., under the trade name Politex. Polishing pads 32 and 34 may be embossed or stamped with a pattern to improve distribution of slurry across the face of the substrate. Polishing station 25c may otherwise be identical to polishing station 25b. A transparent window 279 may be formed in polishing pad 34 over aperture 36.

Although the CMP apparatus is described a vacuum chucking the polishing sheet to the platen, other techniques could be used to secure the polishing sheet to the platen during polishing. For example, the edges of the polishing

sheet could be clamped to the sides of the platen by a set of clamps.

Also, although the rollers are described as connected to the retainers by pins that are inserted through apertures, numerous other implantations are possible to rotatably connect the rollers to the platen. For example, a recess could be formed on the inner surface of the retainer to engage a pin that projects from the end face of the roller. The retainers 160 may be slightly bendable, and the rollers might be snap-fit into the retainers. Alternately, the recess in the inner surface of the retainer could form a labyrinth path that traps the rollers due to tension. Alternately, the retainer could be pivotally attached to the platen, and the roller could engage the retainer once the retainer is locked in position.

In addition, although the CMP apparatus is described as having one rectangular platen with a fixed-abrasive polishing sheet and two circular platens with standard polishing pads, other configurations are possible. For example, the apparatus can include one, two or three rectangular platens. In fact, one advantage of CMP apparatus 20 is that each platen base 170 is adaptable to receive either a rectangular platen or a circular platen. The polishing sheet on each rectangular platen may be a fixed abrasive or a non-fixed abrasive polishing material. Similarly, each polishing pad on the circular platen can be a fixed-abrasive or a "standard" non-fixed abrasive polishing material. The standard polishing pads can have a single hard layer (e.g., IC-1000), a single soft layer (e.g., as in a Polytex pad), or two stacked layers (e.g., as in a combined IC-1000/SUBA IV polishing pad). Different

slurries and different polishing parameters, e.g., carrier head rotation rate, platen rotation rate, carrier head pressure, can be used at the different polishing stations.

One implementation of the CMP apparatus may include two rectangular platens with fixed-abrasive polishing sheets for primary polishing, and a circular platen with a soft polishing pad for buffing. The polishing parameters, pad composition and slurry composition can be selected so that the first polishing sheet has a faster polishing rate than the second polishing sheet.

The CMP apparatus 20 can be used to carry out a large number of multi-step polishing processes. The two-step polishing processes available on CMP apparatus 20 are summarized by the following table:

			1 st Polishing Step			
			rotating pad		advancable sheet	
			fixed abrasive	standard	fixed abrasive	standard
2 nd Polishing Step	Rotating Pad	fixed abrasive	rotating fixed abrasive pad followed by rotating fixed abrasive pad	rotating standard pad followed by rotating fixed abrasive pad	fixed abrasive advanceable sheet followed by rotating fixed abrasive pad	standard advanceable sheet followed by rotating fixed abrasive pad
		standard	rotating fixed abrasive pad followed by rotating standard pad	rotating standard pad followed by rotating standard pad	fixed abrasive advanceable sheet followed by rotating standard pad	standard advanceable sheet followed by rotating standard pad
	advancable sheet	fixed abrasive	rotating fixed abrasive pad followed by fixed abrasive advanceable sheet	rotating standard pad followed by fixed abrasive advanceable sheet	fixed abrasive advanceable sheet followed by fixed abrasive advanceable sheet	standard advanceable sheet followed by fixed abrasive advanceable sheet
		standard	rotating fixed abrasive pad followed by standard advanceable sheet	rotating standard pad followed by standard advanceable sheet	fixed abrasive advanceable sheet followed by standard advanceable sheet	standard advanceable sheet followed by standard advanceable sheet

A computer controller may be coupled to the carousel drive motor to move the carrier heads between polishing stations with the appropriate platen and polishing material to carry out these processes. The processes that include a standard pad can use a polishing pad composed of a polyurethane material with a durable polishing surface (e.g., IC-1000 or Suba-IV).

The invention is not limited to the embodiment depicted and described. Rather, the scope of the invention is defined by the appended claims.

What is claimed is: